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Visual search in school-aged children with unilateral brain lesions

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In this preliminary study, visual search for targets within and beyond the initial field of view was investigated in seven school-aged children (five females, two males; mean age at testing 8 years 10 months, SD 1 year 3 months; range 6 to 10 years) with various acquired, postnatal, focal brain injuries (haematoma, haemorrhage, meningioma, neuroblastoma, and cerebral abscess) in anterior or posterior sites of the left or right hemisphere, and seven control children (matched for age and sex) were also studied. All participants attended mainstream primary schools. The children with lesions underwent surgery after diagnosis (mean age at diagnosis 5 years 4 months, SD 2 years 7 months). Group results indicated that for the overall scores on three psychometric tests of visuospatial and fine motor abilities (Southern California Figure Ground Perception Test, Visual Organization Test, and Visual–Motor Integration Test), no difference between the children with left and right lesions was present. However, children with lesions in the right hemisphere, and not in the left hemisphere, took significantly more time than the controls to locate visual targets presented within and beyond the field of view. Examination of individual data suggested that, in accordance with brain imaging research, right-sided anterior cerebral lesions sustained in early childhood might have an enduring detrimental effect on voluntary visual search performance during development. This persistent effect of early brain injury might imply that developmental plasticity of the brain does not apply to certain specific functions of particular areas of the right hemisphere.

The sparse research focusing on visuospatial abilities of children with focal brain lesions often reveals a differential effect of lesion side in children younger than 6 years (Stiles and Nass 1991, Stiles et al. 1996, Glass et al. 1998, Vicari et al. 1998). Right-sided and not left-sided lesions are associated with visuospatial impairments. However, at school age this effect seems to disappear (Carlsson et al. 1994, Stiles et al. 1996, Paquier et al. 1999). Corresponding developmental findings are reported in studies on verbal competence and IQ: early verbal and IQ impairments related to focal lesions in the left hemisphere seem to diminish at school age (Bates et al. 1999). This disappearance of correlations between lesion side and symptoms reflects, to some degree, the plasticity of the brain in childhood. The assumption is that, after damage to a hemisphere, alternative cortical tissue is capable of taking on the functions of the damaged areas (Bates 1999). Moreover, given the fact that in most studies of focal lesions in children, no relationship is found between particular lesion sites and general deficiencies in visuospatial or verbal behaviour (Vicari et al. 1998, Bates et al. 1999), developmental plasticity of the brain seems to apply to all cerebral areas.

However, recent psychometric studies indicate that early injuries to a hemisphere affect specific visuospatial abilities that persist during development. In two studies, detailed analyses of Block Design test performance and Complex Figure-drawing test performance under a condition of cognitive load showed that specific aspects of visuospatial test performance seem to differ between children older than 6 years with right-hemisphere lesion and those with left-hemisphere lesion (Schatz et al. 2000a, Akshoomoff et al. 2002). Examination of the overall performance on the tests in both studies revealed, as expected, no difference between children with right-hemisphere lesions and children with left-hemisphere lesions. The finding of a continuation with development of subtle deficiencies in visuospatial ability that are the result of selective influences of brain injury suggests limitations on plasticity in the developing human brain (Trauner 2003).

Brain imaging studies in adults reveal that specific sites of the brain are important in particular visuospatial behaviours. Positron emission tomography indicated an involvement of the right superior parietal lobe in the shift of visual attention to the left and right visual field (Corbetta et al. 1993). Functional magnetic resonance imaging studies showed that, under conditions of intentional or voluntary (endogenous) involvement in visuospatial orienting, specific frontal and parietal areas of the brain are asymmetrically (right hemisphere) activated Rosen et al. 1999, Maclin et al. 2001). Thus anterior regions of the right hemisphere seem to be involved in the organization of voluntary visual attention.

Notwithstanding the results of the previous brain imaging research on visuospatial orienting, the study of visuospatial ability in school-aged children with unilateral brain lesions is predominantly dedicated to performance in complex psychometric tests. Research in children with bilateral lesions indeed supports an involvement of the anterior regions of the brain in visual orienting (Craft et al. 1994a,b; Schatz et al. 2000b, 2001). In these studies with children suffering from complex brain injuries, no decisive conclusions could be drawn on the influence of left-hemisphere lesion versus right-hemisphere lesion damage on visual orienting. However, in agreement with the brain imaging results, we might expect that children with focal lesions in frontal or parietal areas of only the right hemisphere will show difficulties in tasks in which voluntary visual attention has to be distributed across the visual field. The aim of the present study, therefore, was to determine whether school-aged children with right-sided anterior cerebral lesions differ in visuospatial orienting from children with focal lesions in other areas of the cortex.

We examined visual search behaviour by means of apparatus used in previous research (Netelenbos and Savelsbergh 2003). This ring-shaped apparatus, which surrounds the child, made it possible to present visual targets within and beyond the initial field of view. For the task the child was asked to visually search for an illuminated target lamp and press a button as soon as the target was localized. By introducing a manual press response, assurance was obtained that the child consciously perceived the target (Posner 1980). The age range of the children with focal cerebral lesions who participated in the study was relatively broad: 6 to 10 years. Control children were matched for age and sex. In particular, the age factor is of relevance here because in the aforementioned study (Netelenbos and Savelsbergh 2003) of children from 5 to 12 years old, we found a clear significant effect for age on localization time.

Method

PARTICIPANTS

Participants included seven children (five males, two females; mean age at testing 8 years 10 months, SD 1 year 3 months; range 6 to 10 years) with heterogeneously acquired left or right unilateral brain lesions (Table I). Children were without general sensory or motor deficits and were treated at the University Hospital in Utrecht, the Netherlands. The children attended mainstream schools so their intellectual abilities can be assumed to be within normal range. The lesions of these children were diagnosed by means of computerized tomography. All children underwent surgery about 3 months before testing. The right-hemisphere lesion group consisted of four children (three females, one male; mean age at testing 8 years 7 months, SD 1 year 7 months); the left-hemisphere lesion group consisted of three children (two females, one male; mean age at testing 9 years 2 months, SD 2 months). Seven non-injured children, matched for age and sex, participated in the study: four right-hemisphere lesion control children (mean age 8 years 8 months, SD 1 year 9 months), three left-hemisphere lesion control children (mean age 9 years 1 month, SD 3 months). The control children were chosen from 50 primary school children who had participated in a previous study (Netelenbos and Savelsbergh 2003). The localization study and standard psychometric tests were performed by the second author. For the children with lesions the experiment and testing took place at the hospital in Utrecht (informed consent of the parents was obtained, and for each child one of the parents was always present during the testing). The study was approved by the hospital review board. Control children were tested in a laboratory room at the Vrije University, Amsterdam. For these children informed consent was obtained from the parents before the experiment was conducted in accordance with the Dutch Institute for Psychologists' guidelines.

ASSESSMENT BY PSYCHOMETRIC TESTS

Information about visuospatial and fine motor abilities of the seven children with brain injuries was provided by the following conventional psychological tests: (1) Southern California Figure Ground Perception Test (Ayres 1972). This test consists of one picture of three shapes drawn one on top of the other. Beneath this picture are six depictions of single shapes. The child has to point out the three shapes in the picture among these six shapes. Eight of these trials were administered. (2) Visual Organization Test (Hooper 1957). The child has to mentally rotate depicted pieces of drawings to be able to recognize the complete drawing. The names of 30 of these scrambled drawings must be given. (3) Visual–Motor Integration Test (Beery 1982). Children have to copy figures, starting with simple stripes and ending with complex three-dimensional figures. The test consists of 24 figures.

As shown in Table II, mean scores for the right-hemisphere lesion and left-hemisphere lesion children were comparable and within normal range. For example, in a normative sample of children of the same age range as the present legion group (6 to 10 years), Seidel (1994) found mean scores for the Hooper Visual Organization Test from 19.4 to 24. Group sizes of the right-hemisphere lesion (n=4) and left-hemisphere lesion children (n=3) permitted the application of non-parametric tests (Siegel 1956). For each of the three psychometric tests, the Mann–Whitney U test (p<0.05) revealed no significant difference between the scores of the right-hemisphere lesion and left-hemisphere lesion children. Thus in accordance with the evidence

Table I: Characteristics of children with unilateral lesions

Participant	*Sex*	*Age at testing (y:m)*	*Age at diagnosis (y:m)*	*Side of lesion*	*Lobe, nature of lesion*
1	M	6:6	5:1	RH	Parietal, epidural haematoma
2	F	7:8	6:7	RH	Occipital, subarachnoidal haemorrhage arteriovenous malformation right of 3rd and 4th ventricle, no hydrocephalus
3	F	10:0	4:3	RH	Frontal, meningioma, and subdural hygroma
4	F	10:0	6:6	RH	Temporal, epidural haematoma after accident
5	F	9:0	6:6	LH	Parietal–occipital, neuroblastoma
6	M	9:2	8:1	LH	Frontal, cerebral abscess and several subdural empyemata
7	F	9:4	0:1	LH	Parietal–temporal, haematoma after accident

LH, left-hemisphere lesion; RH, right-hemisphere lesion.

mentioned in the introduction regarding the overall performance on psychometric tests, a differential influence of lesion side on general visuospatial and fine-motor abilities in school-aged children was not supported.

VISUAL SEARCH APPARATUS

The child sat in the centre of a ring 1.5m in diameter that had 240 equally spaced lamps (12V, 0.1A) on the inside. In this experiment, only eight lamps were used as targets, and one was used as the fixation lamp. The ring was adjustable to the child's eye level by means of three extending legs. The lamps could be separately and soundlessly switched on and off by a computer. The ring was placed in a room under normal fluorescent lighting conditions. The participant held a button connected to the computer in the preferred hand. The button was pressed with the thumb.

VISUAL SEARCH PROCEDURE

When the child was looking at the illuminated fixation lamp located at the midline (0°), the experimenter started a trial. The computer switched off the fixation lamp and simultaneously illuminated a target lamp at one of eight positions in the ring (at angles of 10, 40, 90 and 125°, left and right of the fixation lamp). The child searched for the target and pressed the button when he or she detected it. The pressing of the button switched off the target lamp. Each child was provided with 32 trials, four blocks of eight trials per block (one trial per position). The eight positions per block were presented in a random order. A training block of five trials preceded the experimental trials. For the child the search task was a kind of a game: 'Find the target and switch it off.'

To minimize the unintended effects of outlying scores, in analyses of localization times it is generally recommended to compute medians when relatively few trials per condition are presented. Distributions based on localization times are usually positively skewed and the mean is more affected than the median by outliers. Hence, for each participant we calculated separately the median localization time (the time between switching off the fixation lamp and the pressing of the button at the detection of the target lamp) for the responses to each of the eight target positions. No anticipatory responses with localization times less than 200ms were observed. We found three trials with localization times more than 5 seconds. These trials were considered to be lapse errors and were excluded from analysis. For the 125° target positions clearly falling outside normal children's field of view (Cummings et al. 1988), often the participants initially searched for a target at the side of the ring opposite to the side where the illuminated target was located. Because no illuminated lamp could be detected, the participants then shifted their gaze to the other side of the ring, where the target lamp was to be found. Such 'reversal shifts' have to be expected, because at the start of the trial the child has no clue in which direction he or she has to look to find the target. In comparison with the direct responses, these reversal responses delay the localization time considerably, so the direct and reversal responses for the left and right 125° positions were analyzed separately.

Of importance was the outcome that for the two 125° targets, mean percentage of reversal responses across all children was 46.4%, indicating that the choice of the initial search direction for these targets was a matter of chance. Furthermore, this high percentage reveals that the light emitted from these targets was not visible to the children at the start of a trial. No significant difference (Mann–Whitney U test, $p<0.05$) in mean percentage of reversal responses was found between the seven children with lesions and their controls (50%, SD 26%; and 42.9%, SD 12.2% respectively). Target positions at 90° are located at the border of a child's field of view (Cummings et al. 1988). One child with a right-hemisphere lesion and one child with a left-hemisphere lesion as well as three control children,

Table II: Means (SDs) of visuospatial and fine-motor scores of RH and LH children

Psychometric test	*RH (n=4)*	*LH (n=3)*
Figure Ground Perception (Ayres 1972)	18.3 (4.2)	20.7 (1.5)
Visual Organization (Hooper 1957)	21.1 (5.3)	20.5 (4.3)
Visual–Motor Integration (Beery 1982)	11.8 (5.1)	12.0 (1.7)

LH, left-hemisphere lesion; RH, right-hemisphere lesion.

Table III: Means (SDs) of median localization times (ms) of responses to left and right target positions for lesion and control groups

Localization responses	*RH (n=4)*	*LH (n=3)*	*RH controls (n=4)*	*LH controls (n=3)*
10° direct				
Left	1003 (92)	818 (95)	621 (122)	705 (150)
Right	1028 (238)	843 (64)	621 (109)	706 (119)
40° direct				
Left	1204 (311)	806 (113)	635 (101)	713 (174)
Right	1050 (128)	906 (106)	653 (127)	759 (201)
90° direct				
Left	1646 (583)	1014 (33)	723 (169)	990 (341)
Right	1618 (516)	1120 (57)	825 (223)	1119 (502)
125° direct				
Left	2339 (654)	1190 (148)	1741 (418)	2036 (446)
Right	2294 (476)	1521 (144)	1196 (466)	1576 (272)
125° reversal				
Left	3650 (550)	2279 (191)	2248 (612)	2441 (523)
Right	3070 (996)	2255 (663)	2373 (574)	3036 (26)

RH, right-hemisphere lesion; LH, left-hemisphere lesion.

showed reversal responses for the 90° targets (eight responses in total). These responses were not included in the analyses. The occurrence of such reversal responses might relate to a restricted field of view. However, the proportional distribution of these responses across the lesion and control groups, together with the absence of a relationship between the localization times of the reversal and the direct responses to the 90° targets, seem not to suggest that in the present study, eventual visual pathology in the participants had a decisive role in the localization of peripheral targets.

Results

GROUP ANALYSES

First we examined the effect of hemifield on the localization times. Means and SDs of the median localization times of the children in the lesion and control groups for the left and right target positions are shown in Table III. For each lesion and control group, and for each target position (both for the direct and reversal responses), no significant difference was found between the localization times of the responses to the left and right targets (Wilcoxon matched-pairs signed ranks test, $p<0.05$). Therefore, we decided to collapse the localization times of the responses to the left and right targets for each target position.

Figure 1 presents the means of the median localization times of the lesion groups and their control groups. Inspection of the figure shows that the localization times of the right-hemisphere lesion group were greater than the localization times of the other groups for all localization responses. Mann–Whitney *U* tests supported an involvement of the right hemisphere in the search for visual targets both inside and outside the field of view. In comparison with their control group, the localization times for the direct responses to all target positions of the right-hemisphere lesion group were significantly greater ($p<0.05$). Only for the reversal responses to the 125° targets did the localization times not differ (but with a p value of 0.083). There was no significant difference between the localization times of the children with left-hemisphere lesions and their control group.

These results indicate that, in comparison with normally developing children, children with right-hemisphere lesions need more time to localize visual targets presented within and beyond their initial field of view. Thus, the group analyses suggest that right-hemisphere lesions sustained in childhood have persisting detrimental effects on specific visuospatial abilities. The question remains whether lesion site has a differential effect on visual search behaviour. Because two of the four children with right-hemisphere lesions suffered from anterior cerebral lesions (participants 1 and 3; see Table I), individual analyses might provide support for the hypothesis that, in particular, the anterior regions of the right hemisphere are involved in the distribution of visual attention.

INDIVIDUAL ANALYSES

In Figure 2 individual results of the seven children with lesions are contrasted with the mean medians of the total control group ($n=7$). The figure indicates that for the 125° targets, the median localization times of only the two children with right-hemisphere anterior lesions deviate considerably from the results of the other children with lesions and the total control group. Indeed, a differential

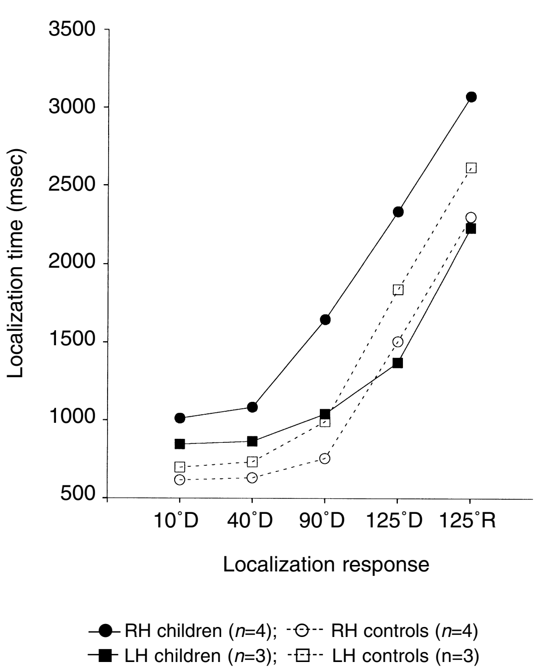

Figure 1: *Means of median localization times of lesion and control groups. LH, left-hemisphere lesion; RH, right-hemisphere lesion; D, direct localization response; R, reversal localization response.*

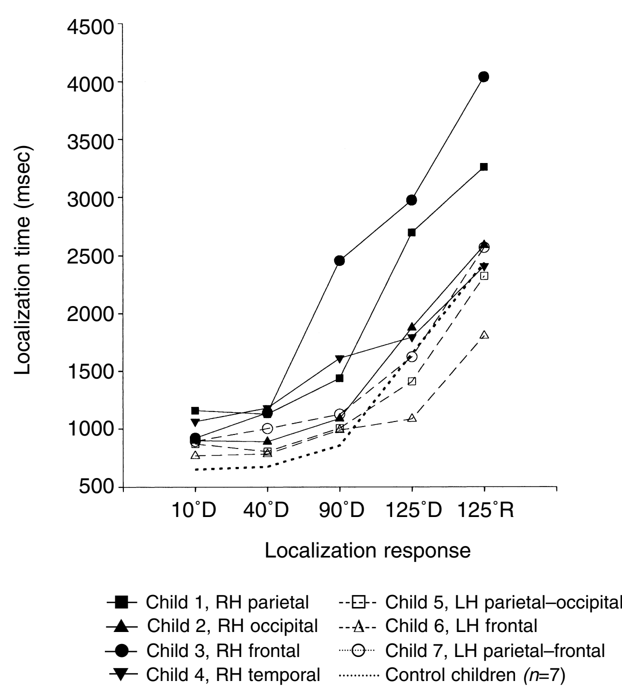

Figure 2: *Median localization times of individual children with lesions and mean medians of total control group. LH, left-hemisphere lesion; RH, right-hemisphere lesion; D, direct localization response; R, reversal localization response.*

effect of lesion site is supported: lesions in anterior regions of the right hemisphere seem to slow down the localization responses, particularly for targets located beyond the initial field of view.

Discussion

In agreement with recent psychometric findings, this preliminary study presents some support for a continuation during the development of subtle impairments in visuospatial ability as a consequence of acquired lesions in the right hemisphere. In comparison with controls, the children with right-hemisphere lesions and not the children with left-hemisphere lesions were relatively slow at locating visual targets presented within and beyond their field of view. In addition, we found support for the supposition that lesions in anterior regions of the right hemisphere might be responsible for impairments in the organization of voluntary visual attention. In school-aged children a frontal or parietal lesion in the right hemisphere sustained after birth seems to have an unfavourable effect on voluntary visual search performance. This conclusion holds especially for the search for targets presented beyond the initial field of view. In comparison with the control children, only both 'critical' children (participants 1 and 3) with right-sided anterior lesions took a relatively long time to localize the 125° targets, whereas the localization times of the children with left-sided lesions in the anterior regions of the brain did not diverge.

The search for a visual target presented within or beyond the initial field of view implies that the observer has to prepare for the possibility that no target is visible at the start of the search. In that case the observer has to apply an endogenous or predictive mode of processing spatial information (Paillard 1987). Under moderate attention focusing conditions, targets presented only within the field of view involuntarily capture attention (Müller and Rabbit 1989) and appeal to an exogenous or sensorimotor mode of processing spatial information (Paillard 1987). The brain imaging studies mentioned in the introduction indicated that specific frontal and parietal areas of the right hemisphere are activated under conditions of endogenous involvement in visuospatial orienting. This right-sided anterior involvement in visuospatial orienting is in accordance with our finding that the localization times of only the two 'critical' children with brain injuries who suffered from lesions in the brain region at issue diverged from the localization times of the control children under clear endogenous conditions, namely when targets have to be found that are out of sight at the start of the search.

The present study has to be considered a preliminary effort to examine the enduring visuospatial difficulties of brain-injured children. Future research might extend our findings in a larger sample of these children with a greater variation in lesion sites. Nevertheless, despite the small number of children, this study contributes to the sparse evidence showing that lesions in the right hemisphere have an enduring effect on voluntary distribution of visual attention. Our results indicate particularly that early frontal and parietal lesions in school-aged children might be responsible for enduring impairments in the search for visual information presented beyond the field of view. This persistent effect of early brain damage suggests that the developmental plasticity of the brain seems not to be unlimited. It might be that when there is injury of 'evolutionarily endowed' functions of particular areas of the right hemisphere, these functions are not transferred to alternative cortical tissue, implying that injuries in those areas have persisting detrimental effects on specific behaviours. Perhaps alternative cortical functions instead of alternative cortical tissues are at the foundation of brain plasticity. This could explain why the initial lag of children with right-hemisphere lesions in overall performance on complex visuospatial tasks disappears during development, whereas specific visuospatial deficiencies in those children persist (Stiles et al. 1996).

Visual search performance is of great relevance to the efficient execution of locomotor behaviour in play, sport, and traffic situations. It is the exception rather than the rule that in these situations essential information from inside the visual field only is to be expected. Results of the present study might, therefore, be considered of relevance to the daily life of children with right-sided anterior cerebral lesions. A relation between proficiency in endogenously manipulating visual attention and motor skill finds support in the literature (see, for example, Goulet et al. 1990, Helsen and Pauwels 1993, Enns and Richards 1997). Thus we could expect our two 'critical' participants to experience difficulties in the execution of locomotor behaviour in complex environments. This supposition needs further inquiry.

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